Cooperative Distributed Problem Solving for Controlling Semi-Autonomous and Autonomous Oceanographic Sampling Networks

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LONG-TERM GOAL

The goal of this program is to develop mechanisms for the adaptive control of a distributed system. This capability will provide the means for an Autonomous Oceanographic Sampling Network (AOSN) [1] to effectively control its group of vehicles and instrument platforms (VIPs) in the face of changing mission requirements, a changing pool of available agents, and a dynamic environment.

OBJECTIVES

The major objectives of this project are to:

- Develop a set of high-level protocols for the organization and reorganization of a group of underwater vehicles and non-mobile instrument platforms (VIPs).
- Design and implement a simulator to model the aggregate behavior of a system of VIPs conducting a mission in accordance with the protocols.
- Develop and conduct experiments on the simulator to show the feasibility of this approach.
- Design and implement VIP capabilities as “generic behaviors”.

APPROACH

This project focuses on the ability of the AOSN to efficiently organize its components and adapt its organization to changes in its situation. A two-tiered approach is used, as shown in Figure 1: a task-level organization (TLO) carries out the tasks of the mission, and a meta-level organization (MLO) designs the appropriate TLO for the particular set of environmental, mission, and AOSN-related features that are present. The MLO provides flexibility and adaptability, freeing the TLO to be designed to be as efficient as possible.

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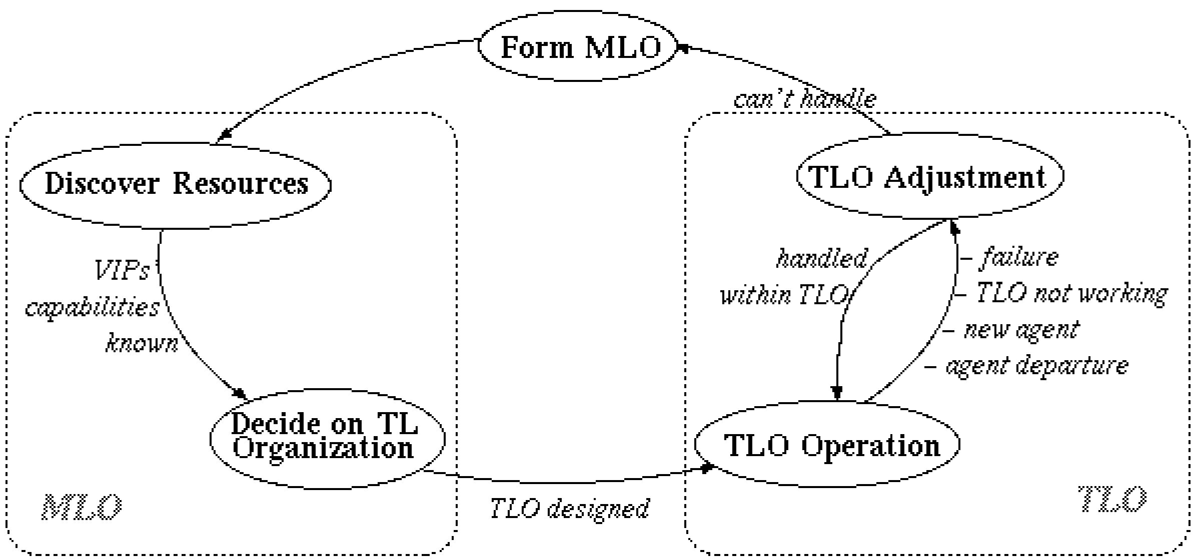

The VIPs taking part in the system can be described using a vocabulary of *generic behaviors* (GBs). This vocabulary is "generic" in the sense that it will be able to describe any VIP, not just vehicles or instrument platforms from particular laboratories. Consequently, any VIP can join the system once it has been described. The AOSN's control mechanism can determine how to use the VIP based on the description, not the internal implementation of those behaviors. GBs will also be the vocabulary for reasoning about organizations.

Our approach also includes a particular perspective on simulation: a multi-fidelity simulator. To avoid the high cost (both in development time and run time) of a high-fidelity simulation or in-water tests, we have developed a simulator that can work at different levels of detail over time to simulate how the protocols work. Initially, it simulates the aggregate behavior of a group of vehicles that are following our protocols. This allows us to test the protocols without the time-consuming development of software, which simulates the reasoning that must be performed by the agents. As parts of the protocols are tested, the reasoning required by agents to carry out those protocols could be developed and simulated. Ultimately, all of the details of the reasoning will be worked out, and simulation will be moved to a high-fidelity simulator.

WORK COMPLETED

Work completed this year falls into the following areas: protocol development; constrained heuristic search; improved multi-fidelity simulation; development of an AOSN testing facility; and implementation of an initial set of GBs.

Spring and summer saw intense work on the organization/reorganization protocols by several student employees and graduate students at UM. Work was done to extend the existing protocol suite, primarily in the areas of agent entry and exit. Whereas before only rudimentary forms of these protocols existed for one problem solving phase (task work phase), now the protocols are essentially complete for all phases of problem solving. Thus agents can now, for example, enter or leave the system during MLO formation, discovery, etc.

Work continued on developing our version of Fox & Sadeh's [2] constrained heuristic search (CHS) for task assignment. Work in the spring focused especially on interleaving task alternative selection

with value selection during constraint propagation and on identifying and eliminating contentions for resources by early commitment of VIPs to task assignments. Both of these techniques are guided by heuristics designed to predict "textures" in the constraint graph being built. Preliminary experiments were performed, which suggested that our approach is much better than the usual approach to such problems; these results are available in the technical report referenced below, and they have been submitted for publication in a journal. Over the summer and fall, a student employee has been working on extending the range of task decomposition trees (ways of representing alternative possible mission configurations) that can be handled by the program. Work later this fall will make use of that when comparing our approach with standard CSP (constraint satisfaction problem) approaches and when adding task alternative selection to such CSP techniques.

The multi-fidelity simulator, now called the Cooperative Distributed AOSN Control (CoDA) simulator, was changed this past year to eliminate the custom C code that had been embedded into CLIPS to perform pieces of the protocols (e.g., task assignment). Instead, the Unix FIFO (named pipes) facility is now used to allow the major portion of the CoDA simulator, written in CLIPS, to communicate with other pieces written in Lisp. The drawback to this approach is that it ties us to Unix and a Common Lisp implementation (we use Allegro CL, from Franz, Inc.). However, this allows us and any other users to use the standard CLIPS distribution without re-compilation. More important, it facilitates fast development and testing of algorithms implementing higher-fidelity simulations of pieces of protocols. The chief example of this is CHS. We now are able to use the actual CHS-based task assignment algorithm, running in Lisp, from the CLIPS simulator. This allows our simulated planner VIP to assign tasks exactly as would an actual VIP in an AOSN.

We have also developed a new testing facility for AOSN research, which we have named the Cooperative AUV Development Concept (CADCON). At the core of this facility, is a distributed multiple vehicle and environment simulation server. In contrast to the above mentioned aggregate behavior simulation, the CADCON simulator operates at a lower level, one, which is based on physics. This provides a very convenient testing harness for GB implementation. A fundamental feature of this facility is that it provides for TCP/IP connectivity among its participants. This enables the interaction of simulation elements, which are distributed over networks ranging from LANs to the Internet. We have implemented the system components on ubiquitous computers: Pentium based machines. This allows us to leverage cheap accessible technology, making remote participation in the simulation by other researchers relatively easy and flexible. In addition, the use of the client/server paradigm and TCP/IP sockets provides a well understood connection model for those interested in developing their own clients. This also provides client developers with a high degree of platform/language independence, thus, allowing distributed researchers to connect their legacy systems, or create new ones in the language and on the platform of their choice. This flexible testing environment, coupled with the simple data exchange mechanism and low-end hardware requirements, should shorten the design-test-redesign cycle needed to create new clients. Further, this connection model provides for easy integration of actual vehicles into the facility.

A methodology for implementing generic vehicle behaviors has been developed and, using it, the GB “Maneuver” has been implemented. This behavior is designed to be used by an AOSN controlling agency to command *any* of its mobile VIPs (regardless of their unique movement capabilities) to specific positions in the sampling network’s volume. It will also be used by VIPs to report their maneuvering capabilities. The Maneuver GB currently operates within the context of the CADCON simulator, which supports different varieties of mobile agents: the slow moving, highly maneuverable, open frame vehicle; and the faster, hydro-dynamically efficient torpedo shaped vehicle. Experiments

with this simulator demonstrate these two different vehicle types behaving in their own particular manners when responding to the generic Maneuver directive.

RESULTS

The results of this year's effort are: (1) a more robust suite of protocols; entry and exit protocols for all problem-solving phases; (2) extension of our CHS-based task assignment algorithm and tight integration of the algorithm with the simulator; (3) experimental results indicating that the task assignment algorithm will be useful; (4) a more flexible multi-fidelity simulator due to linking it to Lisp; (5) a network capable AOSN testing facility; and (6) the realization of a generic Maneuver behavior.

IMPACT/APPLICATIONS

Our work is most directly applicable to AOSNs. Our approach supports the development of AOSNs that can make use of a wide variety of components that may enter or leave at any time. The approach provides a means for AOSNs to self-organize, and it supports the ability of these systems to adapt by giving them a mechanism to reorganize as the situation changes. Our work also supports practical AOSN development by beginning to address the problem of making it possible for any VIP from any lab to be part of the system. The CADCON simulator provides a mechanism for distributed researchers to utilize the Internet to connect their real and/or simulated vehicles into a shared environment.

Our work also has application beyond AOSNs. AOSNs are a particular example of a cooperative distributed problem solving (CDPS) system, which in turn is a kind of distributed AI system. Our work on organization and reorganization will be useful to researchers in distributed AI. In addition, our work on efficient task assignment has required (and continues to require) that we address issues that are important to two areas of artificial intelligence theory, search and constraint propagation.

TRANSITIONS

Information concerning the protocols and the CoDA simulator, along with electronic copies of papers and viewgraphs related to the project, are available to interested researchers via the World Wide Web at the URL:

http://cdps.umcs.maine.edu/CoDA

Information concerning the CADCON multiple vehicle simulator may be found on the AUSI Web site at the URL:

http://www.ausi.org/

From there, two example CADCON client programs may be downloaded and run by interested visitors. Efforts are being made to install the simulation server on a 24/7 machine.

RELATED PROJECTS

1. Creating a task-level organization for an autonomous oceanographic sampling network. PIs: E.H. Turner and R.M. Turner. Funded by contract N0001-14-98-1-0648 from the DEPSCoR program, Office of Naval Research. This project is tightly integrated with the current project. It focuses on task assignment in AOSNs and developing mechanisms for automatic organizational structure selection for AOSNs based on the context.
2. Informativeness Project: Selecting information to volunteer during problem-solving dialogues. PI: E.H. Turner (Funding: National Science Foundation.) Sub-projects:

   - Informational uses of organizational strategies. (Undergraduate students.)
   - Communication between multiagent systems (e.g., AOSNs) and humans (planned future work)

3. Opportunistic reorganization of multiagent systems. (J.H. Lawton, Ph.D. project. Advisors: E.H. Turner and R.M. Turner.)
4. Orca Project: Intelligent mission-level control of oceanographic AUVs. PI: R.M. Turner (Funding: National Science Foundation through 8/98)

REFERENCES

[1] T.B. Curtin, J.G. Bellingham, J. Catipovic, and D. Webb, 1993: “Autonomous oceanographic sampling networks,” *Oceanography*, 6(3).

[2] Mark S. Fox, Norman Sadeh, and Can Baykan, 1989: “Constrained heuristic search,” In *Proceedings of the Eleventh International Joint Conference on Artificial Intelligence (IJCAI-89).*

PUBLICATIONS

Blidberg, D.R., Jalbert, J.C., and Ageev, Mikhail, D., 1998: “Experimental Results; The AUSI/IMTP Solar Powered AUV Project”, MTS Oceans Community Conference, Baltimore MD, November 16-19, 1998.

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